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A DETECTOR FOR LOW ENERGY GAMMA-RAY ASTRONOMY EXPERIMENTS

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SUMMARY

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A detector has been developed specifically for rocket and satellite borne low energy gamma-ray astronomy experiments. This detector consists of a CsI(Tl) crystal,* 2 inches long by 1 inch in diameter, viewed by a single photomultiplier tube together with a CsI(Tl) crystal, 8.75 inches long by 5.75 inches in diameter, viewed by four photomultiplier tubes. The small crystal is inserted into a well of the larger crystal, their two outputs being run in anticoincidence. The output from the small crystal surviving the anticoincidence circuit is fed into a pulse height analyzer. This detector, and its mode of operation, provides a gamma-ray spectrometer that has angular collimation, low background sensitivity, suppression of the Compton continuum, and relatively high photopeak efficiency. Data on the photopeak efficiency, angular response, and suppression of the Compton continuum at various energies are presented. Reasons for using anticoincidence shielding to contend with background problems, rather than bulk shielding with lead, are discussed.

*Cesium iodide crystal activated with thallium.

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INTRODUCTION

Detection of solar gamma radiation in the energy range of 0.1 to 3 Mev and the determination of the shape of the spectrum during both quiet and active solar periods are objectives actively being sought in the solar physics program of the Goddard Space Flight Center. The reason for pursuing these objectives is to examine the possibility of nuclear reactions occurring in the solar atmosphere to generate gamma radiation in this energy interval. The reactions that could perhaps produce a flux observable at the top of the earth's atmosphere (References 1 and 2) are the following:

1. Bremsstrahlung produced by relativistic electrons in the solar atmosphere,
2. Positron annihilation radiation (0.511 Mev), and
3. Deuteron formation through neutron-proton capture reactions (2.23 Mev).

Data obtained in this area would aid in evaluating models of solar flare mechanisms.

EXPERIMENTAL DIFFICULTIES

There is at this time no direct experimental evidence concerning the magnitude of the solar flux to be expected at the top of the earth's atmosphere for the reactions indicated above. Several experiments have successfully detected bremsstrahlung bursts generated by solar flares (References 3 through 7), but these observations were made primarily in the energy range below 0.1 Mev and only with gross energy analysis. Extrapolation from these measurements to the bremsstrahlung flux in photons per square centimeter per second in the 0.1 to 3.0 Mev range would be of questionable validity. It would be beyond the scope of this paper to comment critically on the theoretical estimates of the expected flux, which fall between 0.1 and 0.01 photons/cm^2/sec (References 1, 2, and 8). The detection of a flux of this magnitude demands relatively high performance from the detector used as well as long observation times.

The background flux of gamma radiation observable at the top of the earth's atmosphere has been demonstrated to be of the same order of magnitude as the maximum theoretical estimates for the

*Also published in: "Proceedings of the Eighth Scintillation Counter Symposium, Washington, D. C., March 1-3, 1962," *IRE Trans. on Nuclear Science* NS-9(3):381-385, June 1962.

primary flux.* Consequently, in order to observe the primary flux, it is mandatory that the detector be capable of suppressing this background. The use of lead shielding to reject background and provide angular collimation has proved unsuccessful (Reference 9). Lead will indeed attenuate the atmospherically produced gamma radiation, but apparently lead easily replaces it with its own gamma rays generated through interactions with the primary and secondary cosmic ray beam. In order to circumvent the background problems indicated above, anticoincidence shielding was used in designing the detector.

DESCRIPTION OF DETECTOR

A schematic diagram of the detector is shown in Figure 1. It consists of a CsI(Tl) spectrometer crystal 1 inch in diameter by 2 inches long, inserted into a well bored into a large CsI(Tl) shield

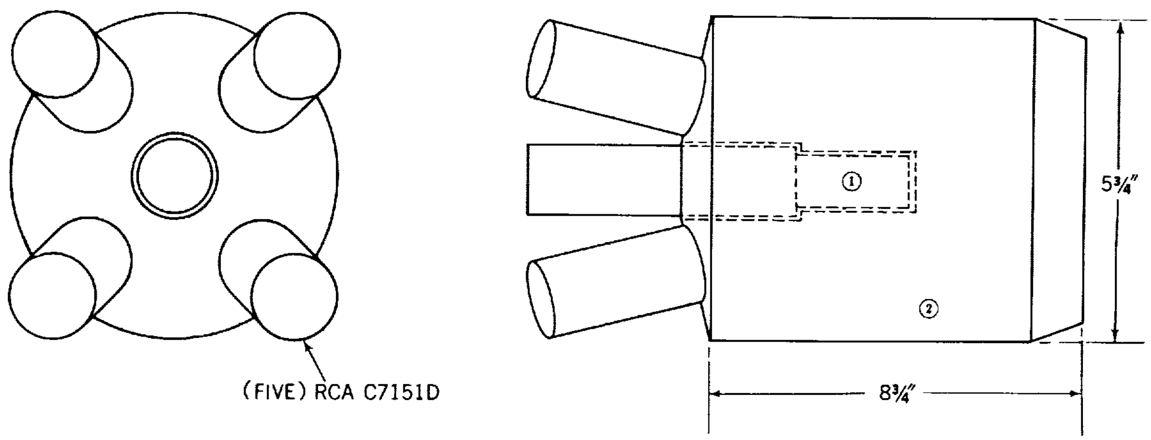

Figure 1—Collimated gamma-ray scintillation spectrometer for energy range 0.1 to 3 Mev. (1) Central CsI(Tl) crystal, 1 inch in diameter by 2 inches long; (2) anticoincidence CsI(Tl) shield crystal for discrimination against gamma rays and charged particles, and suppression of Compton continuum

crystal. The central crystal is viewed by an RCA C7151D "ruggedized" photomultiplier tube. The large shield crystal is viewed by four similar tubes, the outputs of which are added and operated in anticoincidence with the output of the central detector.

The use of the detector in a satellite experiment dictates several design features. Cesium iodide was selected instead of sodium iodide because of its greater physical ruggedness and higher gamma-ray absorption per unit length. A further compromise is the interposition of the phototube into the path of the flux to be observed. This is imposed by weight limitations and the desire to maintain as much thickness of shield behind the central crystal as possible. The detector was fabricated by the Harshaw Chemical Company.

PERFORMANCE OF DETECTOR

Collimation

The angular response of the detector is indicated in Figure 2. These data were obtained by moving a Cs^{137} gamma-ray source in a circle of 24-inch radius around the geometric center of the

*Private communication with Dr. L. E. Peterson, now with Physics Dept., Univ. of Calif.
Unpublished data obtained by K. J. Frost and W. A. White, Goddard Space Flight Center.

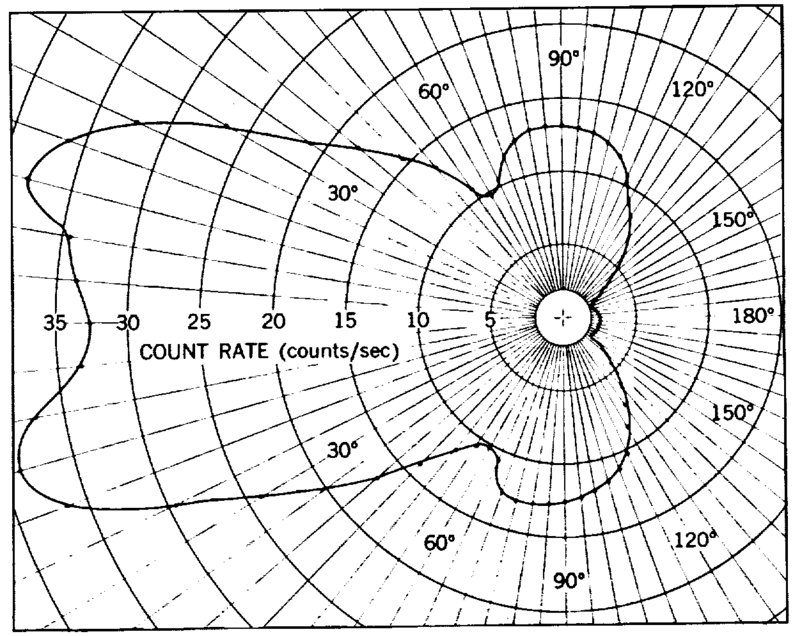

Figure 2—Angular response for photopeak detection of Cs^{137} gamma rays (662 kev)

spectrometer crystal, and counting for 40 minutes at every 5-degree interval. The output pulses of the central detector surviving anticoincidence are analyzed into 128 pulse height intervals. The points plotted represent the count rate integrated over the photopeak using the technique described by Zimmerman (Reference 10). The solid angle, terminated at the points where the detection efficiency is 1/2 its maximum value, is 1.14 steradians. A collimation angle tighter than this would be desirable, and could be accomplished by increasing the length of the shield crystal. However, this was not done in view of weight considerations.

Figure 3 is the Cs^{137} spectrum with the source in the position indicated by 180 degrees on the previous figure. The dashed curve represents data taken with the anticoincidence circuit turned *off*, while the solid curve was taken under the same conditions with the electronics operating normally. The difference between the curves represents photons Compton-scattered into the spectrometer crystal from the shield, and suggests the behavior of an inert shield such as lead.

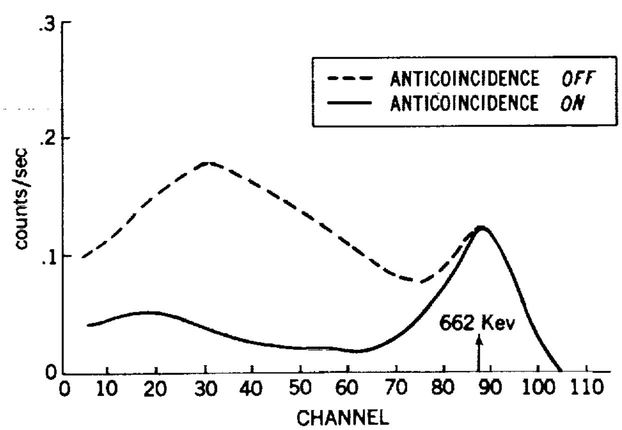

Figure 3—Response of central crystal to Cs^{137} gamma rays passing through the shield

Rejection of Charged Particles

The anticoincidence shielding technique plus pulse height analysis will be 100 percent efficient in the rejection of charged particles. Pulse height analysis will reject all the charged particles that stop in the central crystal without passing through the shield. These events cannot leave less than

3 Mev in the central crystal. Particles passing through the edge of the central crystal and leaving less than 3 Mev cannot avoid passing through the anticoincidence shield. Gamma radiation produced in the shield by a mechanism having a charged particle component will be completely rejected.

The effect of background generated in the shield by the (n, γ) reaction is difficult to evaluate, and we will not attempt to estimate the rate at which this reaction will occur in the Cs, I, and Tl at the top of the atmosphere. The detector will be capable of discriminating against this form of background, for the anticoincidence feature will aid in suppressing it. To evaluate this problem, the detector will be exposed to a neutron beam in the laboratory.

Suppression of the Compton Continuum

Figure 4 demonstrates two performance characteristics that will further contribute to the elimination of background. The annihilation line of Na^{22} was used to obtain these data. The curve marked "bare crystal" was obtained with the central detector operating outside of the shield. Poor geometry and the heavy can assembly contribute to the peaking in the continuum. The two remaining curves were obtained with the assembled detector with the anticoincidence *on* and *off* as indicated. We demonstrate here the suppression of the continuum and the ability of the detector to reject radiation scattered into the central crystal by the shield. Figure 5 indicates the peak-to-continuum ratio for the 1.28 Mev line of Na^{22}.

The elimination of the continuum associated with the 0.511 Mev line is less than ideal. The unit with which the above data were taken has 0.125-inch aluminum and 0.125-inch magnesium oxide between the central crystal and the shield. This is a sufficient amount of matter to absorb a number of the degraded 0.511 Mev photons leaving the central crystal and thus prevent them from registering in the shield. The well in the shield crystal is being modified to incorporate only 0.062 inch of magnesium oxide and a 5-mil-beryllium light baffle.

Response to Gamma-Ray Background Above the Atmosphere

The degree to which the detector will be able to reject the omnidirectional gamma-ray background present at the top of the earth's atmosphere is difficult to predict. The efficiency of the detector varies considerably with the angular position outside the solid angle of acceptance. The angular distribution of the gamma radiation at the top of the atmosphere in the 0.1 to 3 Mev region is not known from experiment. The shape of the pulse height spectrum is well known from recent experiments (Reference 9 and footnote, p. 2). However, the complete absorption and continuum contributions to the spectrum cannot be distinguished. As indi-

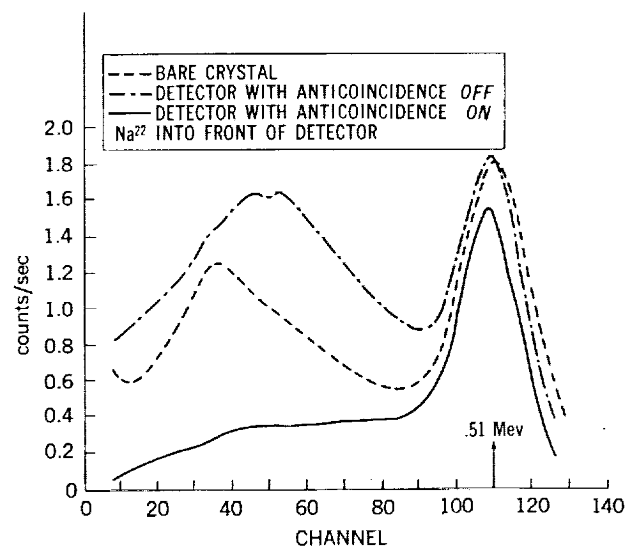

Figure 4—Suppression of the Compton continuum generated within the central crystal

cated earlier, the response of the detector to each of these components will differ.

In the next few months the detector will be sent aloft in a skyhook balloon, to 4 gm/cm^2 residual atmosphere.* A 64 channel pulse height analyzer and a pointing control will be included in the gondola. As a result of this flight it is hoped that both the response of the detector to the atmospheric gamma-ray background and the spatial distribution of this background can be determined in the 0.1 to 3 Mev interval. The balloon flight will be performed in cooperation with Dr. L. E. Peterson of the University of Minnesota.

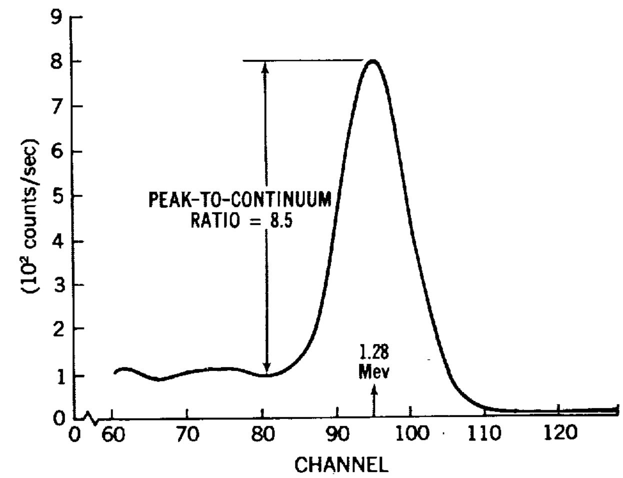

Figure 5—Peak-to-continuum ratio of the 1.28 Mev gamma-ray line of Na^{22}

Efficiency and Resolution

The results of the Monte Carlo calculations of Miller and Snow (Reference 11) for the response of a NaI(Tl) crystal, 1 inch in diameter by 2 inches long, to gamma rays of various energies were used to predict a lower limit to the efficiency of the detector. Since the radiation to be detected must pass through the phototube, an attempt was made to estimate the transmission of the tube and to fold it into the calculations. The resultant curves are shown in Figure 6. The efficiency was measured

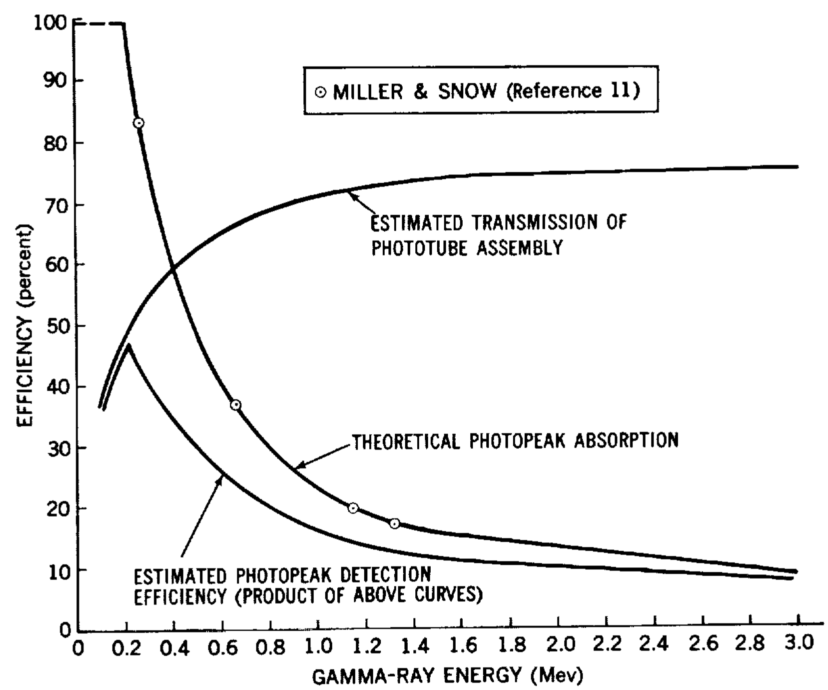

Figure 6—Curves used for estimating efficiency of photopeak detection of central crystal

*Since the writing of this paper, the experiment has been successfully executed.

at the 0.662 Mev line of Cs^{137} and at the 1.28 Mev line of Na^{22}. The strength of the Na^{22} source is known to better than 1 percent, but the Cs^{137} source is calibrated only to ± 20 percent. The measured efficiencies are 18 ± 4 percent at 0.662 Mev, and 13 percent at 1.28 Mev.

Resolution of 19, 16, and 11 percent was obtained for the 0.511, 0.662, and 1.28 Mev lines respectively. This is poorer-than-average resolution and probably reflects the fact than an unselected photomultiplier tube was used to observe the central crystal. Improved resolution will, of course, further increase the peak-to-continuum ratios for these energies.

SATELLITE EXPERIMENT

The experiment for which this detector was designed has been accepted for inclusion in the Orbiting Solar Observatory Satellite to be flown in early 1963. This satellite will be placed into a low altitude equatorial orbit with a useful lifetime of 6 months. The detector will be located in a rotating wheel-like structure of the satellite and will be pointing in an outward radial direction. The wheel serves as a stabilizing platform, and its spin vector will be held normal to the solar vector. The period of rotation of the wheel is 2 seconds. The detector will be gated *on* while the sun is in its field of view, for three successive rotations. The detector will remain *off* for the next three rotations, and the acquired data will be read into a tape recorder. Once every 2 minutes the experiment will collect a background spectrum. The detector will be gated *on* when the wheel has rotated 120 degrees past the point where the sun enters the field of view of the detector. Pulse height analysis of the output of the detector will be accomplished by a 16 channel differential analyzer aboard the satellite.

CONCLUSIONS

The data presented in this discussion represent only the early evaluation stages of the anticoincidence shielding approach to the detector problem in low energy gamma-ray astronomy. A great deal remains to be done in evaluating the present design. In addition to the unit already built, detector modifications are being planned to extend the present observations from 0.020 Mev to 15 Mev. A detector for operation below 100 kev, utilizing a plastic phosphor shield, is being designed. With slight modification the present unit will be rendered capable of operating as a "five-crystal pair spectrometer" (Reference 12) in addition to performing the functions indicated in this paper.

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